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A study of stress reactions of a sectional floating drydock on a docked vessel

Hill, James M.; Perkins, William L.

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A STUDY OF STRESS REACTIONS OF A SECTIONAL FLOATING DRYDOCK ON A DOCKED VESSEL

JAMES M. HILL, JR. AND
WILLIAM L. PERKINS

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A STUDY OF STRESS REACTIONS
OF A
SECTIONAL FLOATING DRYDOCK
ON A
DOCKED VESSEL

Submitted to the Faculty of
Rensselaer Polytechnic Institute
in partial fulfillment of the requirements
for the Degree of
Master of Civil Engineering

by

James M. Hill, Jr.

William L. Perkins

Troy, New York
June, 1950

TABLE OF CONTENTS

FOREWORD . . . .

SYNOPSIS . . . .

INTRODUCTION i

HINGE REACTIONS OF SECTIONAL FLOATING DRYDOCKS . 1

PART I 1

PART II 15

CONCLUSIONS AND RECOMMENDATIONS 23

TABLES 29

APPENDIX A 37

APPENDIX B 39

REFERENCES 40

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FOREWORD

It is hoped that the analysis described herein, together with the accompanying suggestions for further analysis, will be of sufficient value to compensate the many who freely gave their time and knowledge to the authors.

The authors are especially indebted to Mr. A. Amirikian of the Bureau of Yards and Docks for his guidance in the original conception of the problem and on its structural aspects. His understanding of their problems and limitations and his suggestions as to the methods of approach were invaluable.

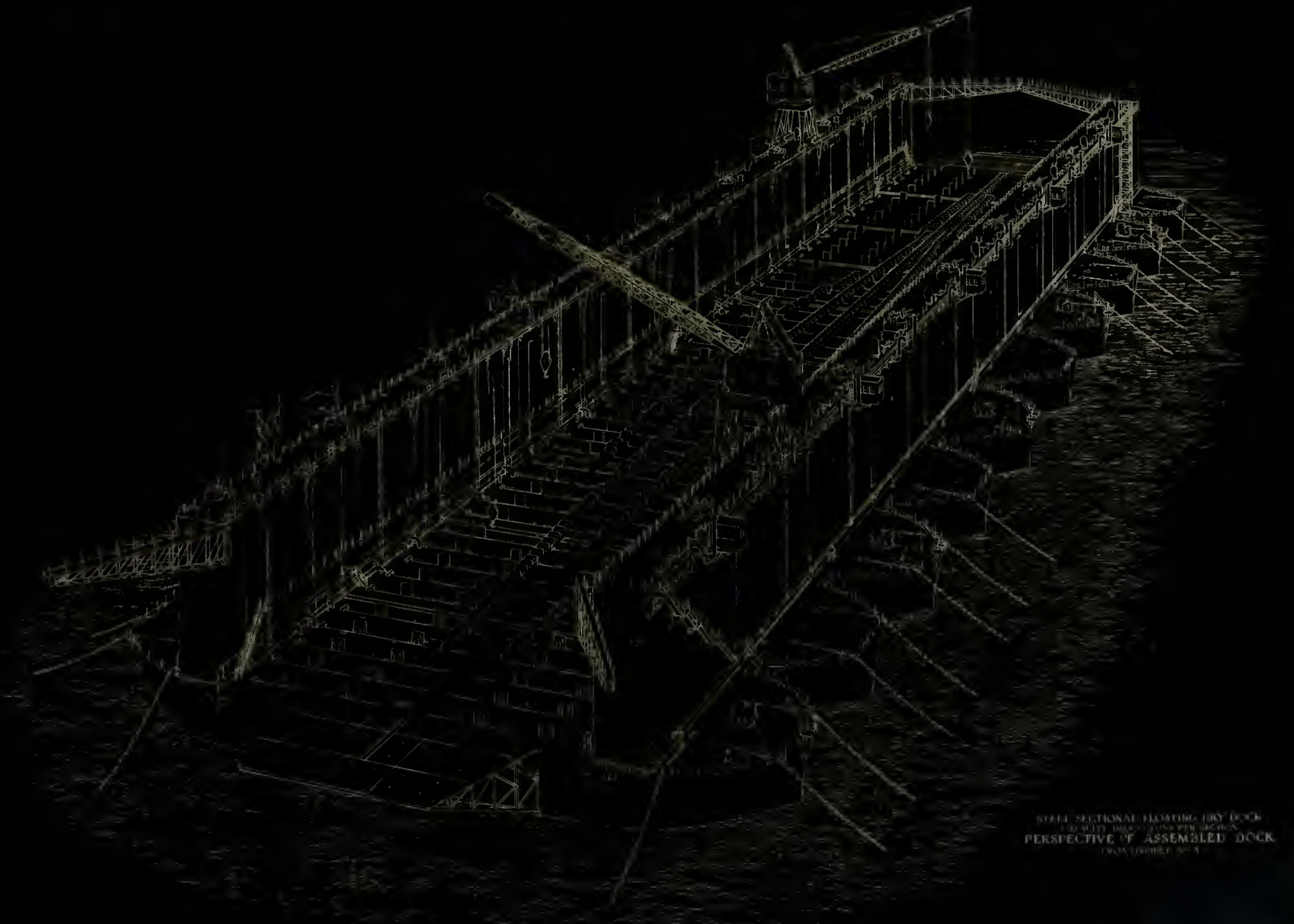
Rear Admiral Lewis B. Combs, Head of the Department of Civil Engineering, Rensselaer Polytechnic Institute, was very helpful in enabling us to obtain information from the several Bureaus of the Department of the Navy which would not otherwise have been available.

Dr. Hui Sien Liu, Assistant Professor in the Department of Civil Engineering, gave many in-

valuable suggestions essential for the completion of this work.

Acknowledgment should go to many others in the Bureau, too numerous to mention, who helped the authors in many ways, and who made the visit to the Bureau by the authors more valuable and enjoyable by their unselfish efforts.

It is the experience of the authors that the Bureau of Yards and Docks, both as an organization and as individuals, is more than anxious to help officers studying at Rensselaer Polytechnic Institute. It is the recommendation of the authors that any officers in postgraduate work who have occasion to consult with the Bureau may do so to their great benefit and complete satisfaction.



STEEL SECTIONAL FLOATING DRY DOCK
CAPACITY [illegible] TONS PER SECTION
PERSPECTIVE OF ASSEMBLED DOCK
FROM DRAWING No. [illegible]

SYNOPSIS

A floating structure consisting of ten sections joined by frictionless pins was assumed. By considering the sections as free bodies and equating the drafts between adjacent sections, influence lines were determined for unit loads at all positions on the structure.

A sectional floating drydock with a particular naval vessel docked thereon and all sections pumped free of ballast was then assumed and the drafts determined at all hinges.

Consideration was then given to the same condition as above but with ballast added to the sections to equalize the live static loads on the various sections and the drafts were determined for this condition.

For the ballasted condition, the resultant forces were found and the moment diagram determined. From this diagram, stresses in the vessel could be found. Considering the moment diagram as a load diagram and using the conjugate beam method the

deflection of the ship could be determined and the previously obtained profile thus checked.

INTRODUCTION

A floating drydock is a buoyant structure capable of picking up ships to enable work on the hull to be carried out in the dry. The mission of a floating drydock is to provide immediate docking facilities in locations where graving docks or marine railways are not available, are not feasible, are of limited capacity, or are only of temporary expediency. Military floating drydocks have been designed to facilitate repairs to all types of naval vessels except the very largest carriers. These drydocks must not only have the structural strength and stability necessary to permit docking of vessels but must also have the requisite characteristics to permit sea towing.

Floating drydocks are of two basic types: the one-piece or rigid dock and the multiple-unit or sectional dock. Many of the existing designs are combinations or modifications of the two basic forms. A rigid dock is a long single section of box girder construction which acts as a unit in lifting a vessel. It gives continuous support and alignment to the ship on the blocks and distributes weight concentrations

along its longitudinal axis. Design of rigid docks is especially suited to docks of small size.

A true sectional dock is an assembly of separate units. The sections are secured together by some locking device which serves as a hinge. When moored alongside a pier or wharf or when moored offshore, the mooring serves to maintain the keelblock centerlines in a common vertical plane. The assembled dock has no overall girder strength, hence gives no continuous support or alignment to the ship on the blocks and does not distribute weight concentrations among the sections.

In any sectional dock, sections not used in picking up a short ship can be disconnected and not used; conversely, additional sections can be of different dimensions and lifting capacities if these differences are desirable. Sections are handled separately in towing and mooring.

Short single sections in a sectional dock need less structural reinforcement on account of longitudinal bending and shear than is required for longitudinal girder strength requirements of long rigid docks. A sectional dock, however, has more transverse bulk-

[illegible]

[illegible]

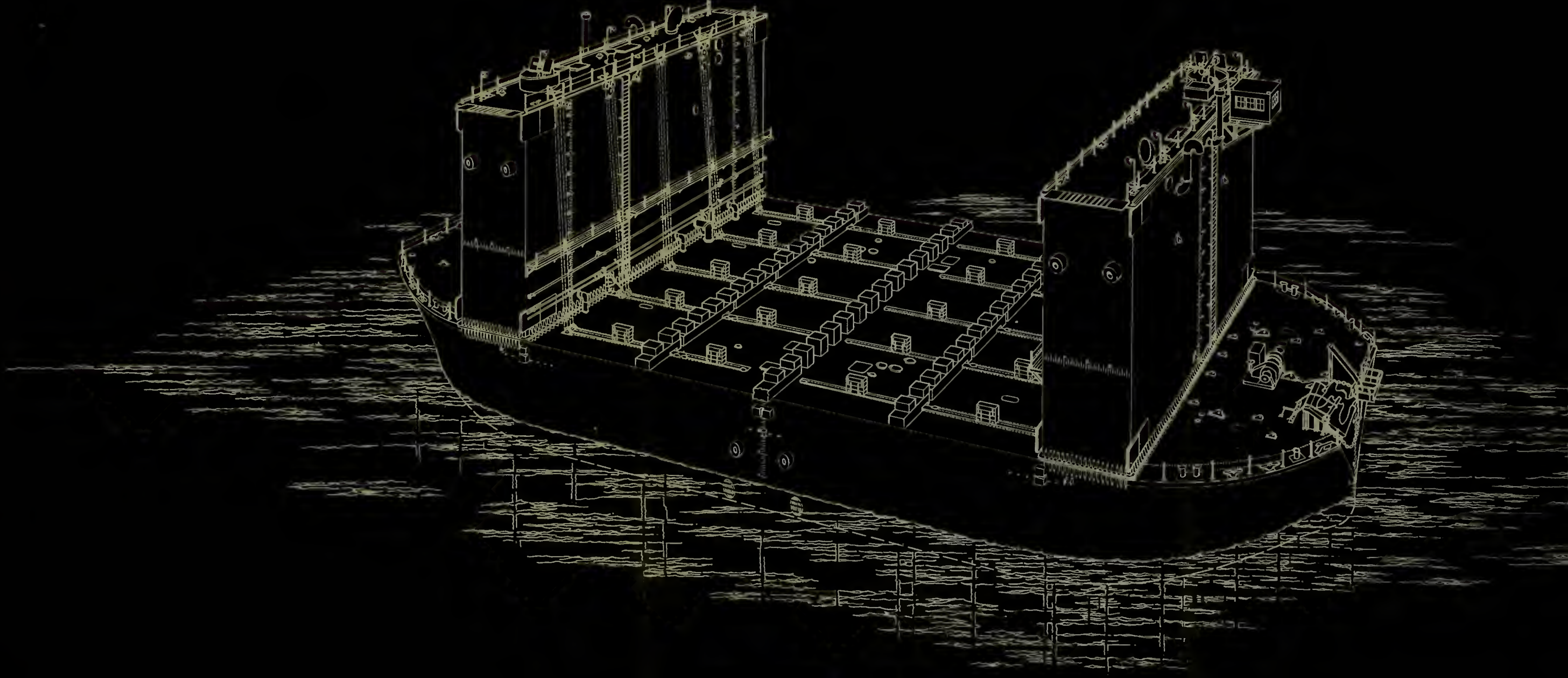
[illegible]

[illegible]

heads and section ends than a rigid dock of equal length, thus there is a saving of material in a rigid dock.

Sections handled as individual units may be so designed that they may transit the Panama Canal, whereas the beam required by a rigid dock would prohibit its passage. Assembly and disassembly of a sectional dock is a lengthy, tedious, and hazardous process. A rigid dock, however, would be immediately available for use upon arrival. Damage to a rigid dock would entirely incapacitate it, but damage to a section of the sectional dock would not prevent the other sections of the dock from operating efficiently.

For the purpose of this thesis, a dock was chosen of the AFDB type (Auxiliary Floating Dock, Big), originally known as the Advance Base Sectional Dock, consisting of ten identical sections, each of 10,000 Tons lifting capacity (See Fig. 2). This dock with sections assembled is 827 feet long with a beam of 256 ft., draft of about 15 ft., and above water height of about 70 ft. This dock is capable of lifting all naval vessels except aircraft carriers of the "Midway" class. The main part of the thesis is general, and applies to any sectional floating



STEEL SECTIONAL FLOATING DRY DOCK
CAPACITY-10 000 TONS PER SECTION
PERSPECTIVE OF SINGLE SECTION IN WORKING POSITION
FRONTISPIECE Nº 2

structure of the form of floating pontoons connected by hinges.

In the original design of the AFDB a true sectional dock was intended with the connections made in such a way that they would act as pins. It was later modified by the addition of welded connecting plates which were intended to make the structure a semi-rigid drydock of box-girder type construction. This attempt was not wholly successful, however, for it was found that these large welded plates worked and showed signs of strain beyond the elastic limit. In addition, it was impossible to disassemble the connecting devices between the sections because they, too, had worked and had been stressed beyond the elastic limit.

Attainment of rigidity was important because of the necessity of maintaining the keel blocks in a fixed, horizontal position while a ship is docked. If the keel blocks remain level, the ship absorbs moment only from the keel block reactions, but if the keel blocks do not remain level, the ship must absorb bending moment caused by differences in slope in adjacent sections. In reality, the AFDB which was

originally designed as a truly sectional dock was never operated as such. The dock was constructed in sections which were towed to the selected site. In assembly the dock was made as rigid a structure as practicable.

A study of the truly sectional drydock which takes no moment between the sections is important in the determination of the stresses to which a ship might be subjected. An injured ship docked in such a sectional dock might be stressed beyond its reduced capacity to absorb strain.

HINGE REACTIONS OF
SECTIONAL FLOATING DRYDOCKS

This work is divided into two main parts. The first part considers the general case of a structure consisting of floats joined in a straight line by hinges and involves determination of hinge reactions for any loading condition. The second part concerns more specifically a particular set of loads corresponding in general to the weight distribution curve of a naval vessel superimposed on a floating drydock in an attempt to determine the stresses in the ship induced by the hinge reactions.

PART I

For the first part, ten pontoons were assumed, all of the same dimensions and displacement and all of them pumped completely dry. It was further assumed that they were connected by frictionless pins with no moment resisting connections between the pontoons. Under the loads applied, no pontoon was considered to come out of the water. There was assumed to be no torsional stress between sections, for all loads were considered to be symmetrical about the longitudinal centerline, and therefore the longitudinal

centerline of the structure remains in a vertical plane. The center of gravity and the center of buyoancy are always considered in the same vertical line regardless of the rotation of the section about its own longitudinal axis.

In a floating structure of the truly sectional type, composed of a number of segments of equal or varying lengths, the connections linking the adjacent sections together may be subjected to considerable strains due to unsymmetrical positions of loading along the longitudinal axis and the buoyant forces. Unknown hinge reactions, the forces developed at the pins, may be determined by first establishing a condition of equilibrium for each segment, then equating the drafts of adjacent sections. This will result in a series of simultaneous equations which must be solved.

For a theoretical discussion, in Fig. 3, (a) shows a four-segment dock under an assumed condition of loading, and (b) shows the drafts of a segment under the various components of loading. By reference to the sketch, a general equation for hinge reaction may be derived as follows:

Draft at right end of Segment 1 = D_{12}

$= d_{w1} + d_{12}^{i} + d_{12}^{ii} + d_{12}^{iii} + d_{12}^{iv}$ in which (1)

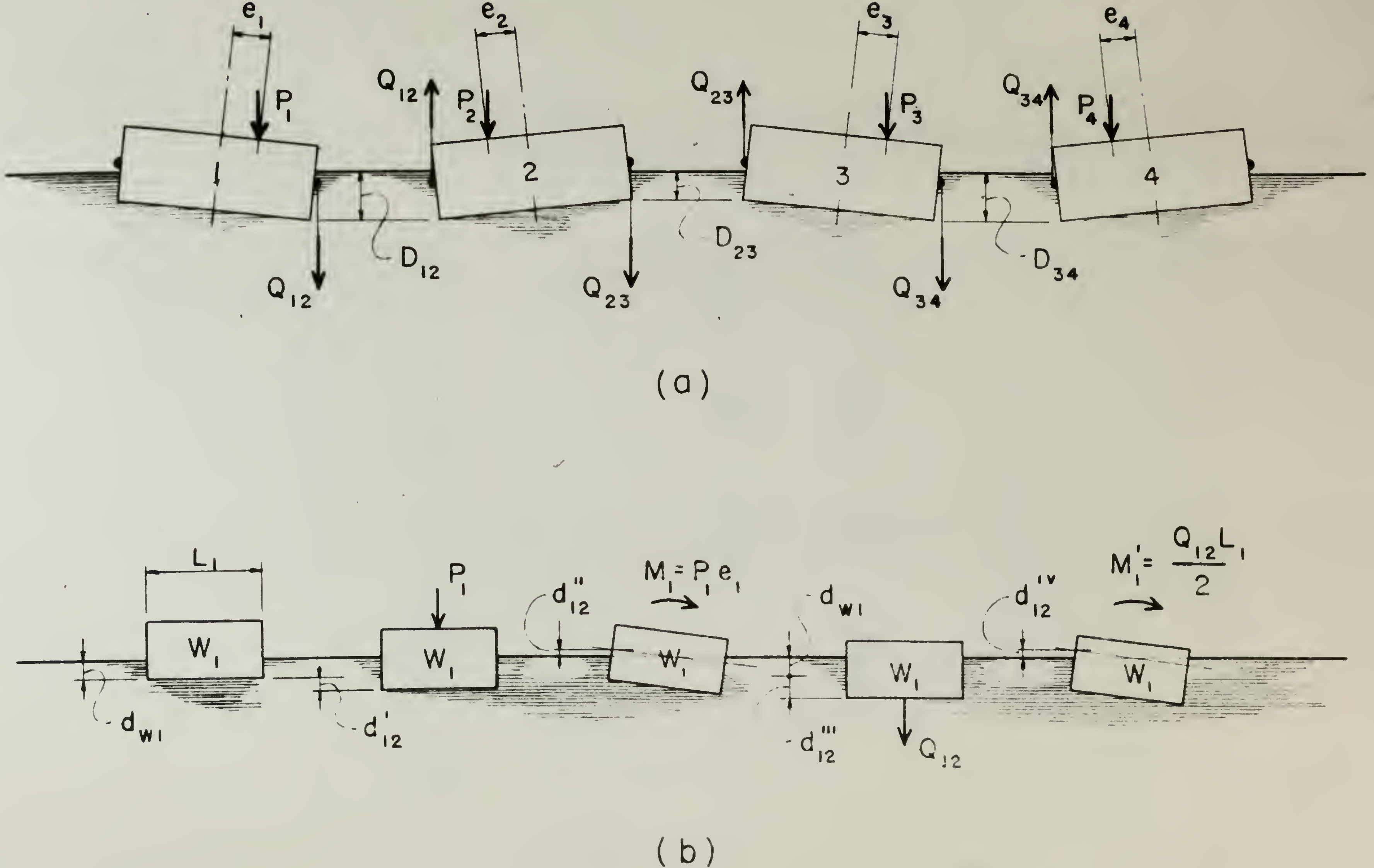

e_1
e_2
e_3
e_4
P_1
P_2
P_3
P_4
Q_{12}
Q_{23}
Q_{34}
1
2
3
4
D_{12}
D_{23}
D_{34}
Q_{12}
Q_{23}
Q_{34}
(a)
L_1
P_1
$M_1 = P_1 e_1$
$M_1' = \frac{Q_{12} L_1}{2}$
d_{12}''
d_{w1}
d_{12}^{iv}
W_1
d_{w1}
d_{12}'
d_{12}'''
Q_{12}
(b)

Fig. 3

d_{w1} - draft caused by dead weight

d^{i}_{12} - draft caused by live load

d^{ii}_{12} - draft caused by eccentricity of the live load

d^{iii}_{12} - draft caused by shear between seg. 1 & 2

d^{iv}_{12} - draft caused by eccentricity of above shear

Hence:

$$d_{w1} = \frac{W_1}{wbL_1}, \quad d^{i}_{12} = \frac{P_1}{wbL_1}, \quad d^{ii}_{12} = \frac{6P_1e_1}{wbL_1{}^2}$$

$$d^{iii}_{12} = \frac{Q_{12}}{wbL_1}, \quad d^{iv}_{12} = \frac{3Q_{12}}{wbL_1} \quad \ldots\ldots\ldots \quad (2)$$

where b is the width of the segment, L the length, W the displacement, P the live load applied, and w is the weight of a unit volume of water.

d^{iii}_{12} is derived from $\frac{f}{w} = \frac{Mc}{wI} = \frac{Pec}{wI} = \frac{Pe\ {}^{L}/_{2}}{wbL^3/_{12}} = \frac{6Pe}{wbL^2}$

d^{iv}_{12} is derived similarly, for $e = L/_2$

and

$$\frac{6Q_{12}e}{wbL^2} = \frac{6Q_{12}L}{wbL^2 .2} = \frac{3Q_{12}}{wbL}$$

Similarly, draft at left end of segment 2 = D_{12}

$$= d_{w_2} + d^{i}_{21} + d^{ii}_{21} - d^{iii}_{21} - d^{iv}_{21} + d^{v}_{21} - d^{vi}_{21} \ \ldots \ (3)$$

in which terms are similar to those on the preceding page:

$$d_{w_2} = \frac{W_2}{wbL_2}, \quad d^{i}_{21} = \frac{P_2}{wbL_2}, \quad d^{ii}_{21} = \frac{6P_2e_2}{wbL_2^2}, \quad d^{iii}_{21} = \frac{Q_{12}}{wbL_2}$$

$$d^{iv}_{12} = \frac{3Q_{12}}{wbL_2}, \quad d^{v}_{12} = \frac{Q_{23}}{wbL_2}, \quad d^{vi}_{21} = \frac{3Q_{23}}{wbL_2} \quad \ldots\ldots\ldots \quad (4)$$

Equating equations (1) and (3)

$$1/L_1 \left[W_1 + P_1\left(1+\frac{6e_1}{L_1}\right)+Q_{12}(1+3)\right] = 1/L_2 \left[W_2 + P_2 \left(1+\frac{6e_2}{L_2}\right)-Q_{12}(1+3)+Q_{23}(1-3)\right]$$

or

$$Q_{12}(1+3)\left(\frac{1}{L_1} + \frac{1}{L2}\right)-Q_{23}\frac{1-3}{L2} + \frac{W_1}{L1}-\frac{W_2}{L_2}+\frac{P_1}{L_1}\left(1-\frac{6e_1}{L_1}\right)-\frac{P_2}{L_2}\left(1+\frac{6e_2}{L_2}\right) = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

If the blocks are made the same length, eq. (5) which may be designated as the hinge force relation between segments 1 and 2, will assume the simplified form:

$$8Q_{12}+2Q_{23}+W_1 - W_2 + \left(1+\frac{6e_1}{L}\right)P_1 - \left(1+\frac{6e_2}{L}\right)P_2 = 0 \quad ..(6)$$

Relations for the unknown hinge reactions at the other locations may be obtained similarly. Thus, between segments 2 and 3:

$$8Q_{23}+2Q_{34}+2Q_{12}+W_2-W_3+\left(1+\frac{6e_2}{L}\right)P_2-\left(1-\frac{6e_3}{L}\right)P_3 = 0 \quad . \; . \quad 6(a)$$

Between segments 3 and 4:

$$8Q_{34}+2Q_{23}+W_4-W_3+\left(1+\frac{6e_3}{L}\right)P_3-\left(1+\frac{6e_4}{L}\right)P_4 = 0 \quad . \; . \; . \; . \quad 6(b)$$

The values of the three unknown hinge reactions, namely, Q_{12}, Q_{23}, and Q_{34} are then obtained from the solution of equations (6), 6(a), and 6(b).

The structure being considered consists of ten sections as stated before, and since these sections are identical, the equations above are much simplified. The solution of hinge reactions could be presented in a number of ways, but influence lines were used because of their simplicity and their ease of application to this problem. Influence lines permit the presentation of the general case. Once they have been obtained, application of specific cases is facilitated by superimposing ship weight distribution curves on these influence lines.

Figure 4 shows an elevation of the various positions of the unit load which were used in obtaining the influence lines of the hinge reactions. As shown in the figure, unit loads were placed at each end of each section at a differential distance from the hinge. It was assumed that an increase in draft caused an increase in shear and this was considered positive (+). The sign convention for hinge reactions assumed that both hinge reactions on a particular section acted in a clockwise direction. The assumption was also made that the influence line is a straight-line function between load points on any section.

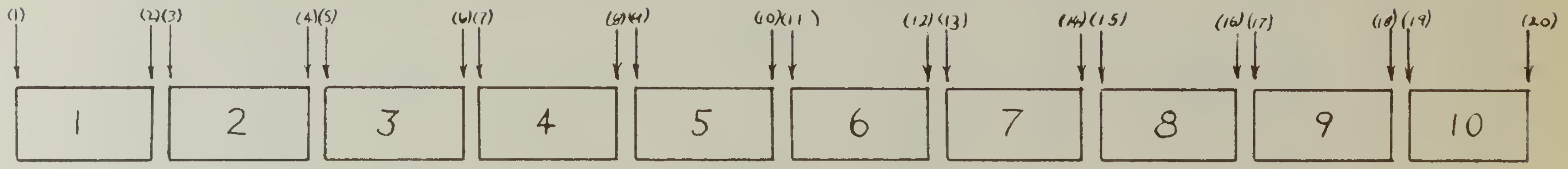
Considering the load at position (2), and referring to equation (1), the following was obtained with section 1 as a free body:

$$D_{12} = d_{w1} + d_{12}^{i} + d_{12}^{ii} + d_{12}^{iii} + d_{12}^{iv}$$

From equation (2), it follows that:

$$D_{12} = \frac{W_1}{wbL_1} + \frac{P_1}{wbL_1} + \frac{6Pe_1}{wbL_1^2} + \frac{Q_{12}}{wbL_1} + \frac{3Q_{12}}{wbL_1}$$

Next section 2 was considered as a free body, and the load was considered at the same position as before, giving the following:



SKETCH OF LOAD POSITIONS

Fig 4

$$D_{21} = d_{w2} + d^{i}_{21} + d^{ii}_{21} - d^{iii}_{21} - d^{iv}_{21} + d^{v}_{21} - d^{vi}_{21}$$

From equation (4), it follows that:

$$D_{21} = \frac{w_2}{wbL_2} + \frac{P_2}{wbL_2} + \frac{6P_2 e_2}{wbL^2_2} - \frac{Q_{12}}{wbL_2} - \frac{3Q_{12}}{wbL_2} + \frac{Q_{23}}{wbL_2} - \frac{3Q_{23}}{wbL_2}$$

Equating the drafts, $D_{12} = D_{21}$, and:

$$\frac{w_1}{wbL_1} + \frac{P_1}{wbL_1} + \frac{6P_1 e_1}{wbL_1^2} + \frac{Q_{12}}{wbL_1} + \frac{3Q_{12}}{wbL_1} = \frac{w_2}{wbL_2} + \frac{P_2}{wbL_2}$$

$$+ \frac{6P_2 e_2}{wbL_2^2} - \frac{Q_{12}}{wbL_2} - \frac{3Q_{12}}{wbL_2} + \frac{Q_{23}}{wbL_2} - \frac{3Q_{23}}{wbL_2}$$

All sections were identical, however, and $e = L/2$, $P_1 = 1$, and $P_2 = 0$, therefore:

$$1 + 3 + Q_{12} + 3Q_{12} = -Q_{12} - 3Q_{12} + Q_{23} - 3Q_{23}$$

or

$$8Q_{12} + 2Q_{23} + 4 = 0 \quad \ldots\ldots\ldots \quad (7)$$

Substituting in equation (6) gives the same result.

Consideration of the load at position (3) was the next step. In a manner similar to the above, and with section 1 as a free body:

$$D_{12} = d_{w1} + d^{i}_{12} + d^{ii}_{12} + d^{iii}_{12} + d^{iv}_{12}$$

From equations (2):

$$D_{12} = \frac{W_1}{wbL_1} + \frac{P_1}{wbL_1} + \frac{6P_1e_1}{wbL_1^2} + \frac{Q_{12}}{wbL_1} + \frac{3Q_{12}}{wbL_1}$$

Considering section 2 as a free body and the load still at position (3):

$$D_{21} = d_{w2} + d^{i}_{21} + d^{ii}_{21} - d^{iii}_{21} - d^{iv}_{21} + d^{v}_{21} - d^{vi}_{21}$$

From equation (4):

$$D_{21} = \frac{W_2}{wbL_2} + \frac{P_2}{wbL_2} + \frac{6P_2e_2}{wbL_2^2} - \frac{Q_{12}}{wbL_2} - \frac{3Q_{12}}{wbL_2}$$

$$+ \frac{Q_{23}}{wbL_2} - \frac{3Q_{23}}{wbL_2}$$

Equating the drafts, $D_{12} - D_{21}$, and:

$$\frac{W_1}{wbL_1} + \frac{P_1}{wbL_1} + \frac{6P_1e_1}{wbL_1^2} + \frac{Q_{12}}{wbL_1} + \frac{3Q_{12}}{wbL_1} = \frac{W_2}{wbL_2} + \frac{P_2}{wbL_2}$$

$$+ \frac{6P_1e_2}{wbL_2^2} - \frac{Q_{12}}{wbL_2} - \frac{3Q_{12}}{wbL_2} + \frac{Q_{23}}{wbL_2} - \frac{3Q_{23}}{wbL_2}$$

As above, all sections were identical, and $e = L/2$ $P_1 = 0$, and $P_2 = 1$, therefore:

$$Q_{12} + 3Q_{12} = 1 + +3 - Q_{12} - 3Q_{12} + Q_{23} - 3Q_{23}$$

or

$$8Q_{12} + 2Q_{23} - 4 = 0 \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (8)$$

Equations (7) and (8) are identical except for the difference in the sign of the constant. This difference is caused by the change in direction of the shear as the unit load crosses the hinge point.

Next the load was considered at position (1), and the following was obtained with section 1 as a free body:

$$D_{12} = d_{w1} + d^{i}_{12} - d^{ii}_{12} + d^{iii}_{12} - d^{iv}_{12}$$

From equation (2):

$$D_{12} = \frac{w_1}{wbL_1} + \frac{P_1}{wbL_1} - \frac{6P_1e_1}{wbL_1{}^2} + \frac{Q_{12}}{wbL_1} + \frac{3Q_{12}}{wbL_1}$$

Considering section 2 as a free body and with the load still at position (1):

$$D_{21} = d_{w2} + d^{i}_{21} + d^{ii}_{21} - d^{iii}_{21} - d^{iv}_{21} + d^{v}_{21} - d^{vi}_{21}$$

From equation (4):

$$D_{21} = \frac{W_2}{wbL_2} + \frac{P_2}{wbL_2} + \frac{6P_2e_2}{wbL_2^2} - \frac{Q_{12}}{wbL_2} - \frac{3Q_{12}}{wbL_2}$$

$$+ \frac{Q_{23}}{wbL_2} - \frac{3Q_{23}}{wbL_2}$$

Equating the drafts, $D_{12} = D_{21}$, and:

$$\frac{W_1}{wbL_1} + \frac{P_1}{wbL_1} - \frac{6P_1e_1}{wbL_1^2} + \frac{Q_{12}}{wbL_1} + \frac{3Q_{12}}{wbL_1} = \frac{W_2}{wbL_2}$$

$$+ \frac{P_2}{wbL_2} + \frac{6P_1e_1}{wbL_2^2} - \frac{Q_{12}}{wbL_2} - \frac{3Q_{12}}{wbL_2} + \frac{Q_{23}}{wbL_2} - \frac{3Q_{23}}{wbL_2}$$

As above, all sections were identical, and $e_2 = L/2$, $P_1 = 1$, and $-P_2 = 0$, therefore:

$$+1 - 3 + Q_{12} + 3Q_{12} = -Q_{12} - 3Q_{12} + Q_{23} - 3Q_{23}$$

or

$$8Q_{12} + 2Q_{23} - 2 = 0 \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (9)$$

Demonstration of resulting equations when considering two more load positions is necessary. Assuming the load at position (3) and equating the drafts between sections 2 and 3, the following results:

$$D_{23} = \frac{W_2}{wbL_2} + \frac{P_2}{wbL_2} + \frac{6P_2e_2}{wbL^2_2} - \frac{Q_{12}}{wbL_2} + \frac{3Q_{12}}{wbL_2} + \frac{Q_{23}}{wbL_2}$$

$$+ \frac{3Q_{23}}{wbL_2}$$

$$D_{32} = \frac{W_3}{wbL_3} + \frac{P_3}{wbL_3} + \frac{6P_3e_3}{wbL^2_3} - \frac{Q_{23}}{wbL_3} - \frac{3Q_{23}}{wbL_3} + \frac{Q_{34}}{wbL_3}$$

$$- \frac{3Q_{34}}{wbL_3}$$

Since P_2 and P_3 equal 0, and $D_{23} = D_{32}$:

$$-Q_{12} + 3Q_{12} + Q_{23} + 3Q_{23} = -Q_{23} - 3Q_{23} + Q_{34} - 3Q_{34}$$

or

$$2Q_{12} + 8Q_{23} + 2Q_{34} = 0$$

In the above manner, the following sets of simultaneous equations were produced, first with the load at position (4) and then with the load at position (5). With the load at position (4), the following resulted:

$$8Q_{12} + 2Q_{23} = +2$$

$$2Q_{12} + 8Q_{23} + 2Q_{34} = -4$$

$2Q_{23} + 8Q_{34} + 2Q_{45} = 0$

$2Q_{34} + 8Q_{45} + 2Q_{56} = 0$

$2Q_{45} + 8Q_{56} + 2Q_{67} = 0$

$2Q_{56} + 8Q_{67} + 2Q_{78} = 0$

$2Q_{67} + 8Q_{78} + 2Q_{89} = 0$

$2Q_{78} + 8Q_{89} + 2Q_{9-10} = 0$

$2Q_{89} + 8Q_{9-10} = 0$ . . . . (10)

With the load at position (5), the following set of equations resulted:

$8Q_{12} + 2Q_{23} = 0$

$2Q_{12} + 8Q_{23} + 2Q_{34} = +4$

$2Q_{23} + 8Q_{34} + 2Q_{45} = +2$

$2Q_{34} + 8Q_{45} + 2Q_{56} = 0$

$2Q_{45} + 8Q_{56} + 2Q_{67} = 0$

$2Q_{56} + 8Q_{67} + 2Q_{78} = 0$

$2Q_{67} + 8Q_{78} + 2Q_{89} = 0$

$2Q_{78} + 8Q_{89} + 2Q_{9-10} = 0$

$2Q_{89} + 8Q_{9-10} = 0$ . . . . (11)

All other sets of equations were identical except that the constants shifted position with respect to the variables, therefore they are not shown here. This similarity of equations considerably simplified the solution of the problem.

A typical solution of one set of simultaneous equations is included as Appendix A. Other solutions were all produced by the same procedure.

The ordinates of the influence lines obtained from the solutions of the nine sets of nine simultaneous equations are shown in Table I. Graphs of these influence lines are shown in Fig. 5.

These equations were solved by the method developed by Grinter in his text on structures.
There are a number of other methods of solution, probably the simplest of which is given in "Analysis of Rigid Frames" by A. Amirikian of the Bureau of Yards and Docks, Department of the Navy.

On page 6 the assumption was stated that the influence line is a straight-line function between load points on any section. It is easily demonstrated that this assumption is right. In order to find the point where the influence line crosses the axis of abscissas, reference is made to equation (6):

Influence Lines of Hinge Reactions

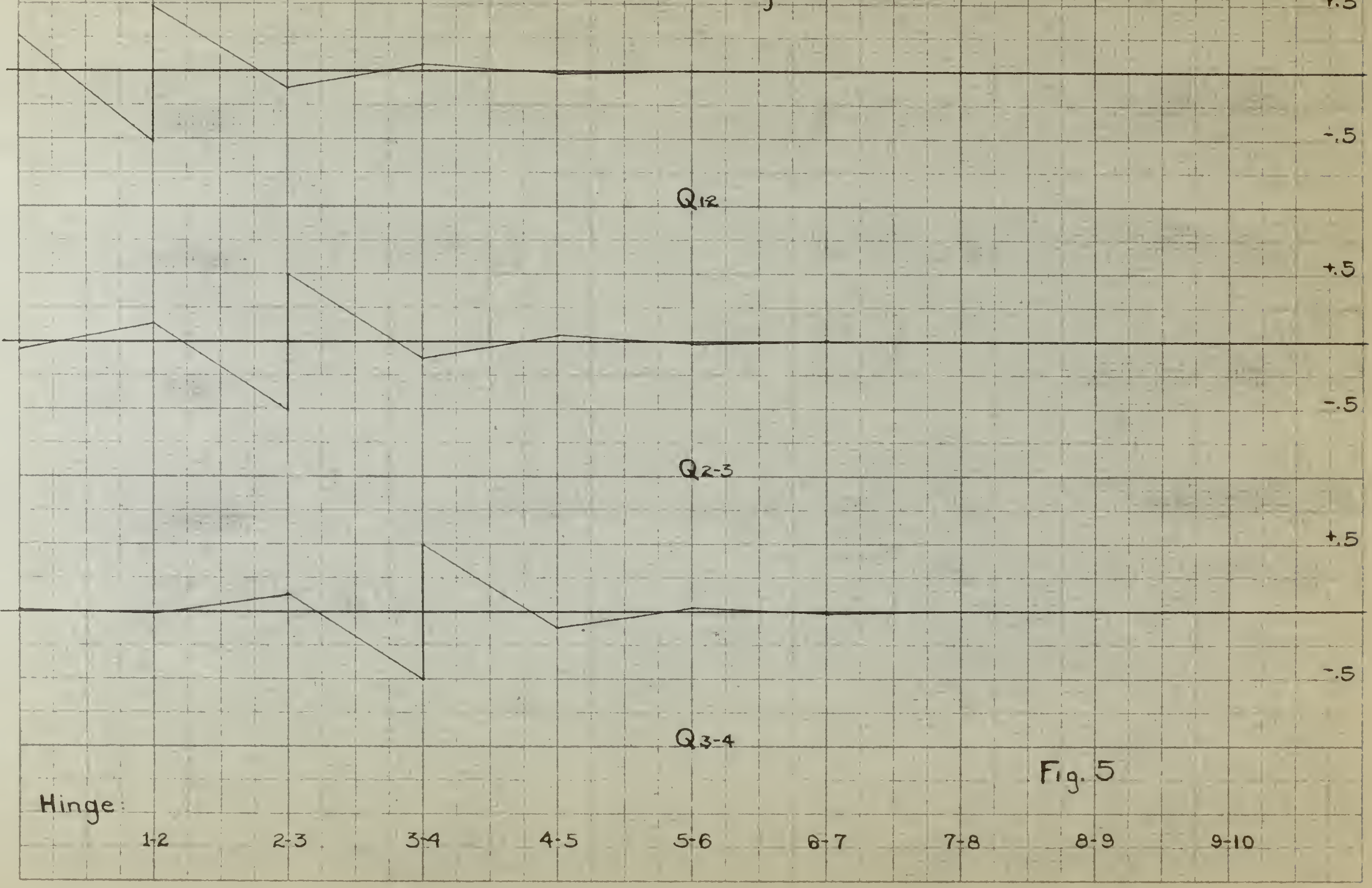


Fig. 5

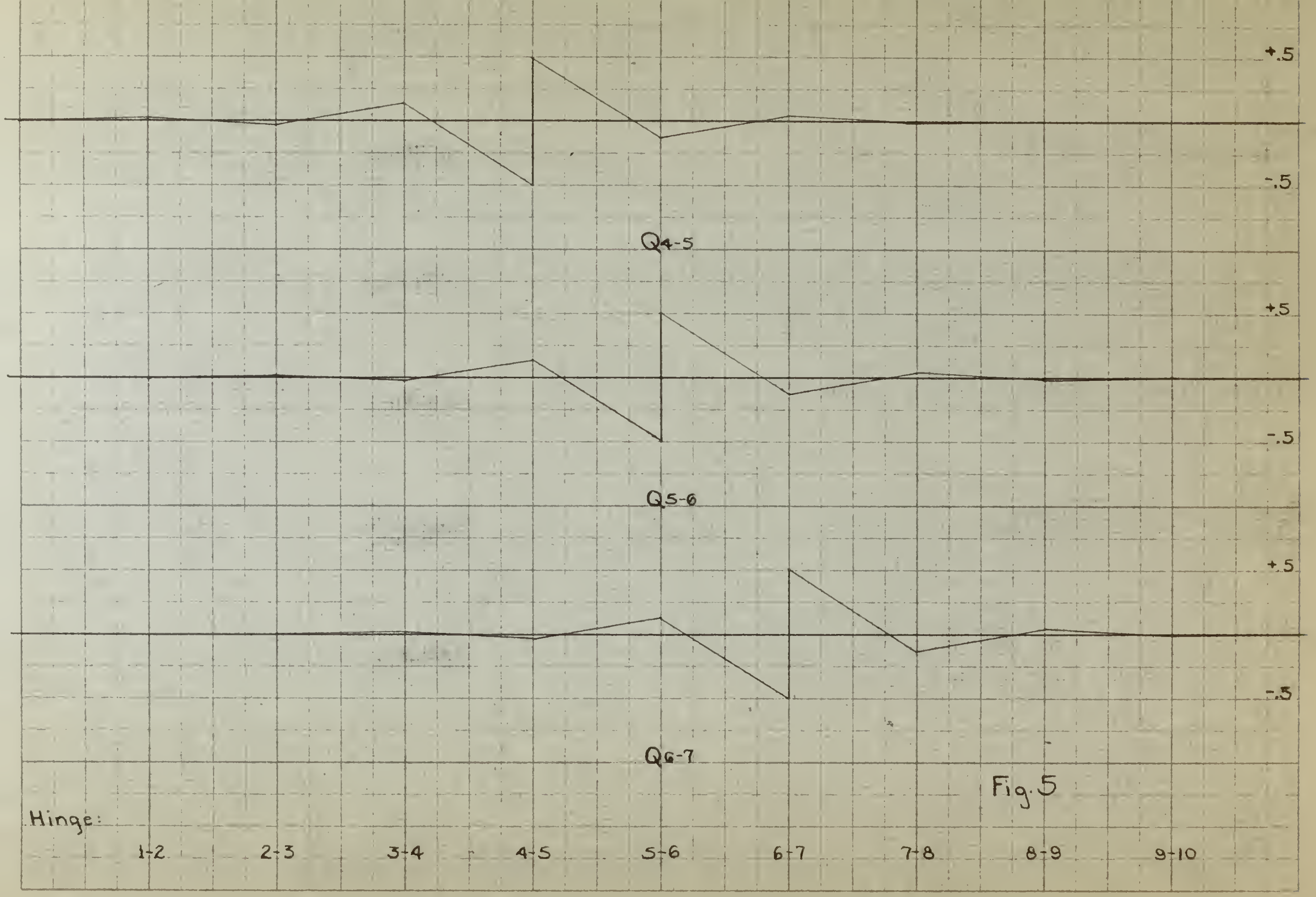


Fig. 5

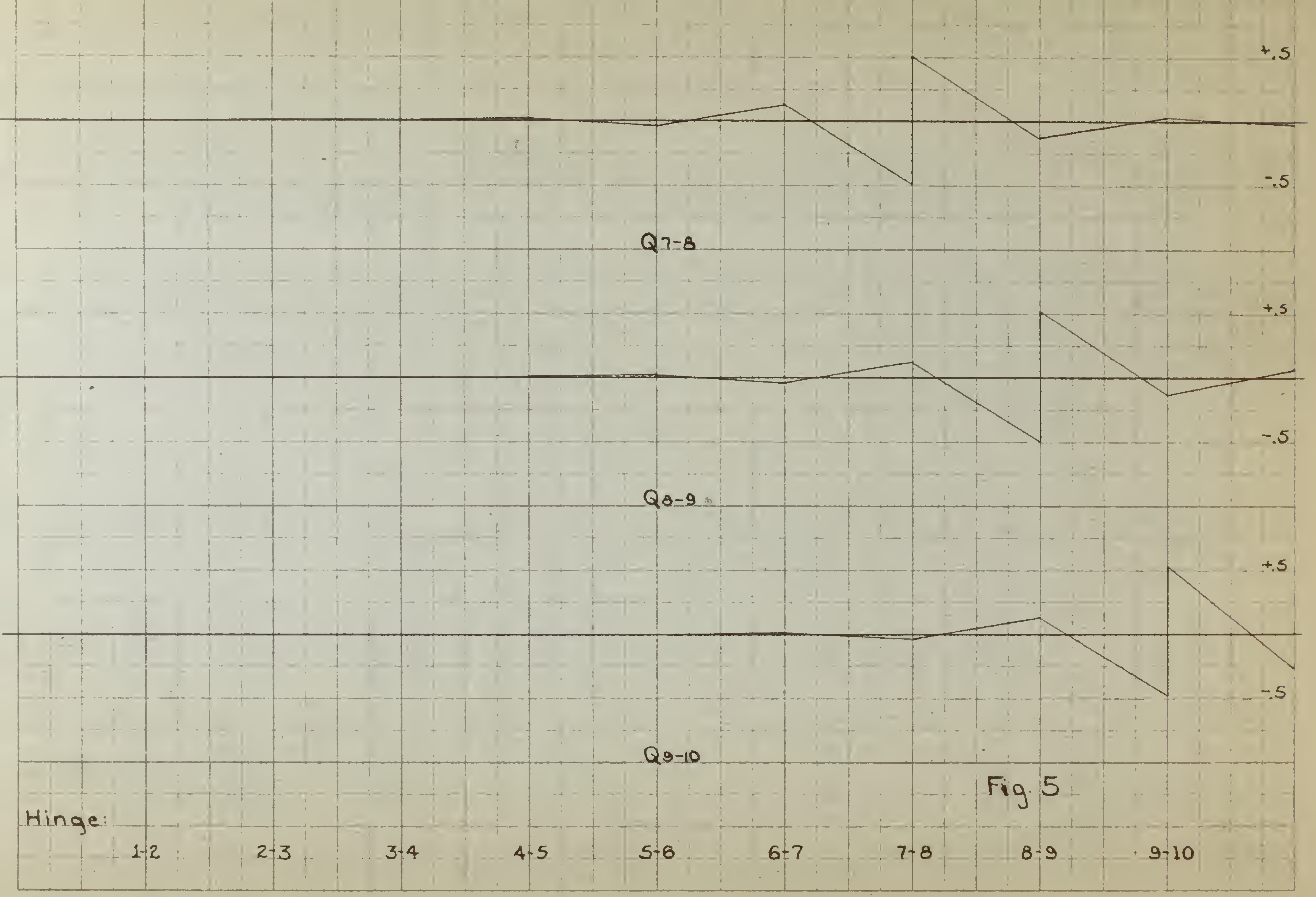


Fig. 5

$$8Q_{12} + 2Q_{23} + W_1 - W_2 + (1+6e_1/L)P_1 - (1+6e_2/L)P_2 = 0$$

In every case, the ordinate at the right end of section 1 is opposite in sign and twice the magnitude of that at the left end. It therefore follows that a straight line joining these ordinates would cross the axis at L/3 from the left end, or at $e = -L/6$. Furthermore, when the unit load is at this point, all shears are equal to 0. With this in mind, and since $P_1 = 1$, $P_2 = 0$, and $W_1 = W_2$, equation (6) becomes:

$$(1+6e/L)1=0$$

Therefore, $e = -L/6$

By examining the influence lines it can be seen that the hinge reaction at the fourth hinge in either direction from the load point is less than one percent of the hinge reaction at the load point. From this it can be seen that increasing the number of sections to more than ten would not materially affect the hinge reactions.

With these influence lines it is possible to solve for any hinge reaction by applying loads as determined from the weight distribution curves of any particular vessel. The procedure for this is demonstrated in the second part of this thesis.

PART II

The determination of stresses induced in a docked vessel by hinge reactions was approached by applying a typical weight distribution curve of a naval vessel to the influence lines obtained in Part I. Although the work in this part involved the application of a specific set of loads, the procedure involved principles which are the same regardless of the vessel docked. Two conditions of pumping were considered. First, it was assumed that none of the sections contained water, and second, water was assumed to be added to the sections as necessary to equalize the loading.

This problem considered specifically the AFDB assembled as a truly sectional dock. Individual sections of this dock are 80 ft. by 256 ft., and hinges are 83 ft. center to center. (See Fig. 1.) Dead load displacement of individual sections is 3810 long tons or 8534.4 Kips.

A weight distribution curve of a particular naval vessel was obtained from the Bureau of Ships, Depart-

ment of the Navy, but for security reasons it cannot be reproduced here. The area of this curve was divided into segments 83 feet long which corresponded to the distance between hinges. It was assumed that all of the load represented by the area of a particular segment acted upon the section beneath it and that there was no load carry-over to adjacent sections. Overhang at the bow and stern was considered to be transmitted to the end sections by shoring. The center of gravity of each portion of the area was determined and it was assumed that the load corresponding to the area was applied to the section through the center of gravity. These loads and their eccentricities are shown in Columns 1 to 4 of Table II.

The loads thus obtained were applied to the influence lines in order to find the hinge reactions. By the simple application of similar triangles, the ordinates at the point of application of these loads were determined for each influence line. These ordinates are given in Table III. Multiplying these ordinates by the appropriate loads and adding algebraically gave the shears or hinge reactions which are shown in Table IV. Sign convention as already stated must be carefully followed in order to find the correct directions for the hinge reactions.

Equation (1) from Part I was as follows:

$$D_{12} = d_{w_1} + d^{i}_{12} + d^{ii}_{12} + d^{iii}_{12} + d^{iv}_{12}$$

or

$$D_{12} = \frac{W_1}{wbL_1} + \frac{P_1}{wbL_1} + \frac{6P_1e_1}{wbL_1} + \frac{Q_{12}}{wbL_1} + \frac{3Q_{12}}{wbL_1}$$

Since the dead load, live load, eccentricity, and shear are now known, the equation can easily be solved for the draft. By this method, drafts between all sections and at the ends of the dock can be determined. A typical solution is included as Appendix B. The resulting mean drafts are tabulated as Table VI. A check on the work thus far is obtained by solving for corresponding drafts on adjacent sections which must be the same if the work is correct.

In the unwatered condition, the profile as shown in Figure 6 is quite irregular. This irregularity is impractical since it is likely to induce excessive stress in the docked vessel.

All types of modern floating drydocks are compartmented and the operational procedure requires partial pumping of the various compartments in an attempt to obtain load uniformity. The next step in this problem was the addition of water to most of the

sections in order to obtain the same live load on each section as on the section which had the maximum live load in the unwatered condition. These additional loads are shown in Column 5 of Table II. These water loads were considered to act through the center of gravity of the section and the free surface effect was neglected. If a horizontal profile resulted, these assumptions would not be unreasonable, and a horizontal profile is the objective of this process of adding water ballast. Other conditions were the same as before, and the problem was solved in the same manner. The shears or hinge reactions obtained are shown in Table V, and the resulting mean drafts are shown in Table VI. The profile of the watered condition is shown in Fig. 3 and is still irregular but the irregularities are not as great as in the unwatered condition.

It is conceivable that greater compartmentation of the sections would further reduce the irregularities in the profile. These compartments would have to be arranged so each section could be trimmed in the longitudinal direction of the dock. Further investigation of pumping procedures for a sectional drydock with compartmented sections in an

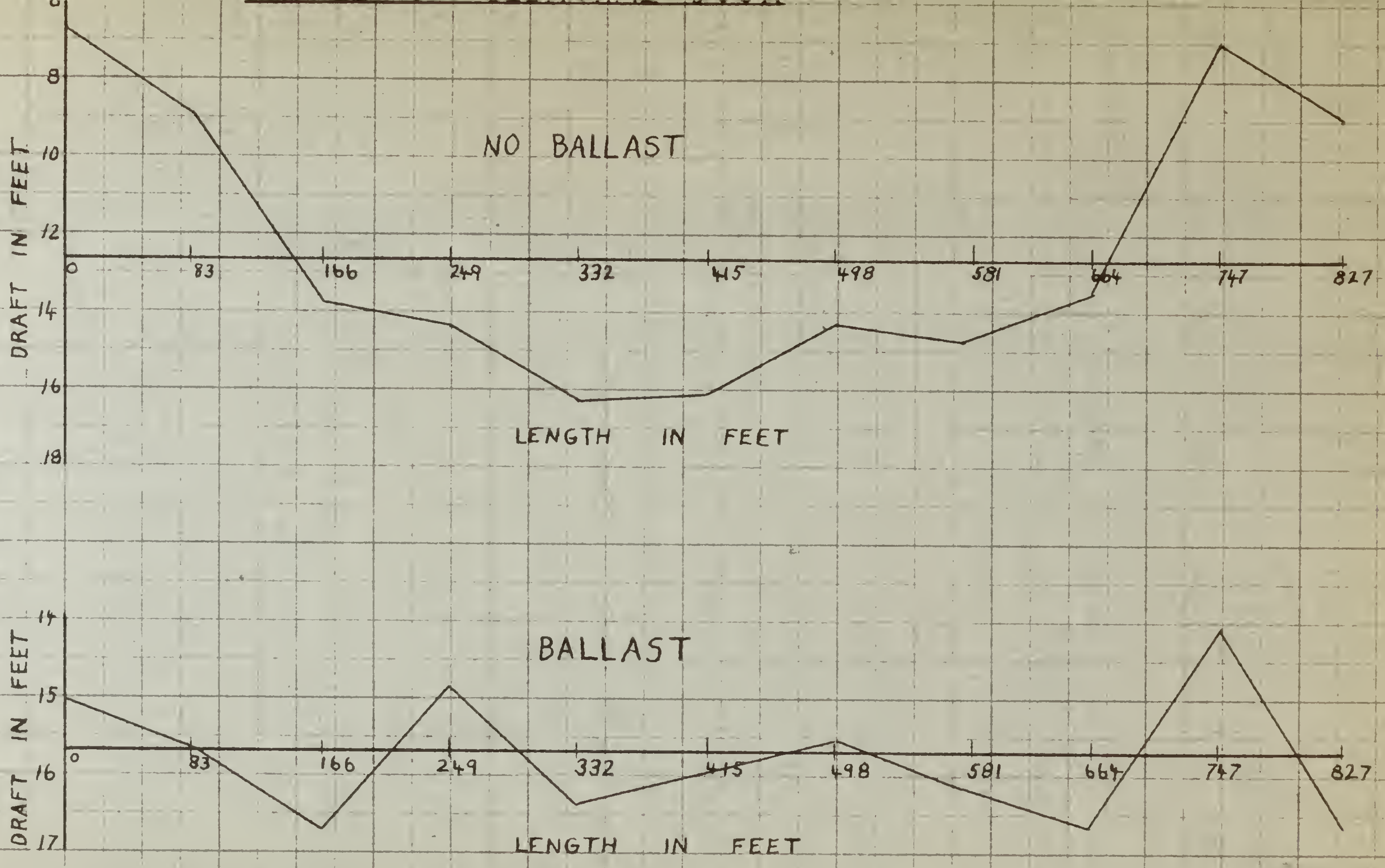

NO BALLAST
DRAFT IN FEET
8
10
12
14
16
18
0
83
166
249
332
415
498
581
664
747
827
LENGTH IN FEET
BALLAST
DRAFT IN FEET
14
15
16
17
0
83
166
249
332
415
498
581
664
747
827
LENGTH IN FEET

Fig. 6

attempt to obtain a less irregular profile with consequent less induced stress would be of great value. This investigation, however, considered no compartmentation in the sections but concerned itself with determining the induced moments in the docked vessel for this partially pumped condition alone.

The next step was to determine the resultant forces corresponding to each pontoon section. Since the supported ship is not subdivided or cut into separate slices as assumed in the beginning of this analysis, free motion of the individual pontoons cannot occur. In other words, once the ship rests on the section of the dock, all the tilts in the individual segments will align themselves into a curve or line corresponding to the bottom of the ship. As a result, there will be little or no shear left at the hinge connections. The resultant force, therefore, will be the net shear which has now been removed from the dock by the rigidity of the ship. These forces are given in Table VII. This can also be shown mathematically as follows:

Forces acting on a section are - -

P - Live load and dead load.

W - Ballast.

B - Buoyant force.

ΔV - Net shear on section.

F - Resultant force.

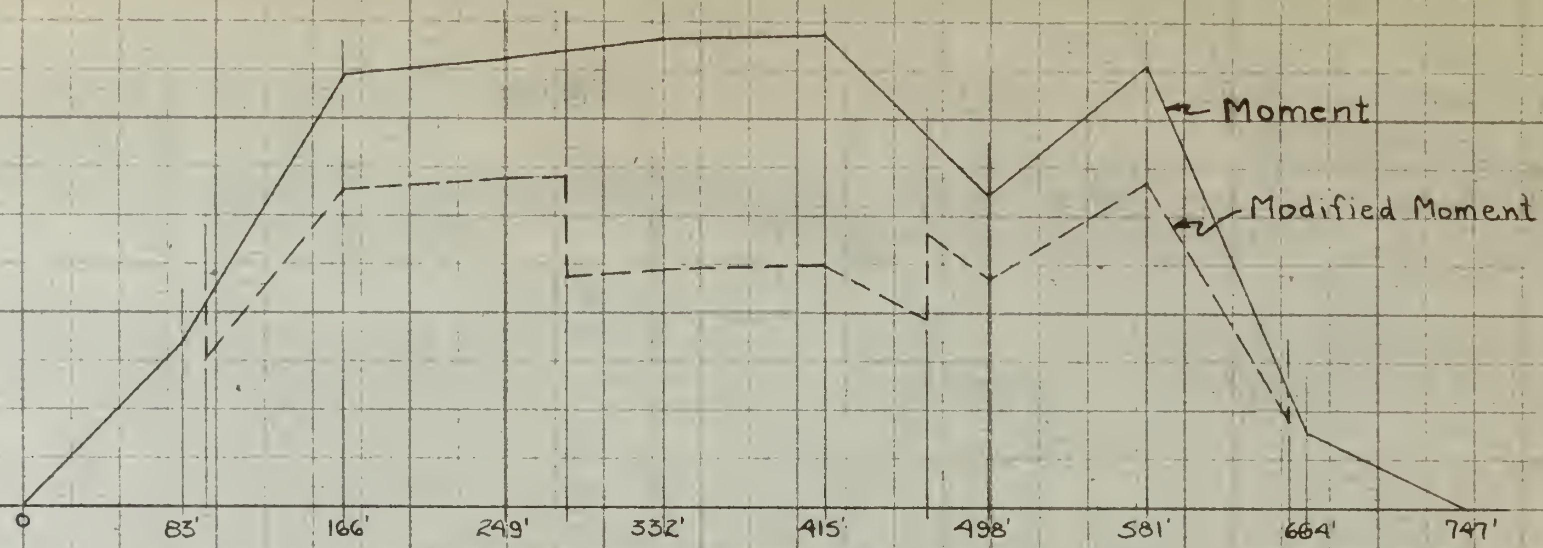
$P + W - B + \Delta V = 0$ from equilibrium conditions stated in analysis

$F = P + W - B$ since shear is transmitted to docked vessel

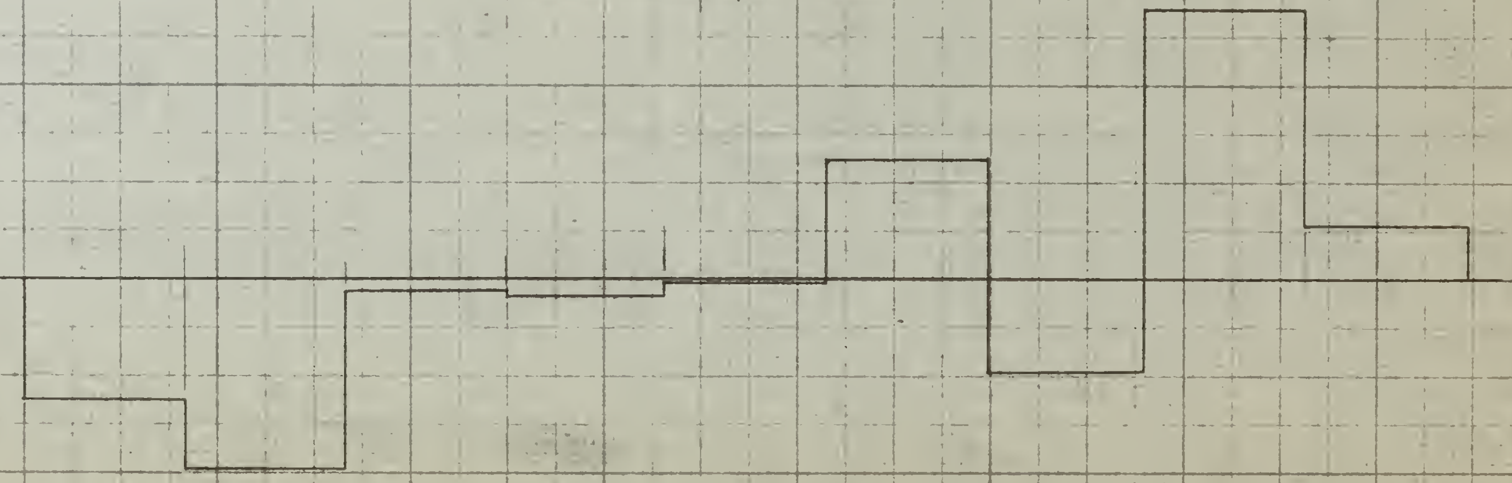
Therefore $F = \Delta V$ See Fig. 6

The shear diagram of these resultant forces is shown in Fig. 7 .

The bending moment diagram was obtained by integration of the shear diagram and is also shown in Fig. 7 and in Table VII. From the moments thus computed, the stress induced in the ship at any point can be easily calculated if I and c or S is known. Those persons who design the drydocks, however, are not as concerned with stresses as they are with the limiting values of bending moment.



Moment Diagrams



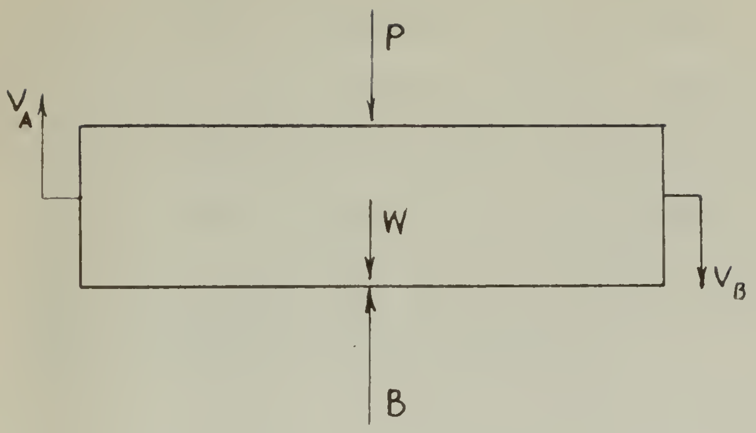
Shear Diagram

Fig. 7

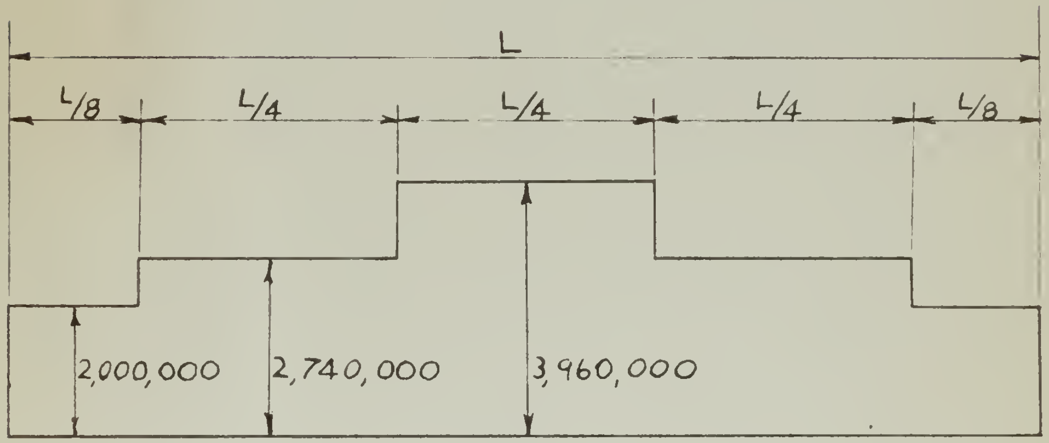
For the semi-rigid drydock, the limiting bending moment was to be 500,000 foot-tons. The maximum value computed in the above procedure was 73,700 foot-kips, which is less than one-tenth of this limitation.

It is desirable to check the above computations. A simple method of doing this is to compare the profile previously obtained with a deflection curve calculated from these values of moment by the conjugate beam method. The extent of coincidence of these two curves would indicate the degree of accuracy obtained in the solution. Corrections in the form of additional ballast or reduced ballast in the affected pontoons would be governed by the extent of the divergence of the two curves.

In order to use the conjugate beam method, it was necessary to obtain the M/EI diagram from the moment diagram. The ship considered did not have a constant I throughout its length. Fig. 8 shows the distribution of the moment of inertia which was used in modifying the moment diagram. Moments of inertia in the end portions of the ship were not obtainable, but a reasonable value was assumed and is shown on



FREE BODY DIAGRAM



MOMENTS OF INERTIA

Fig. 8

the graph. The M/EI diagram is shown in Fig. 7.

From the M/EI diagram a deflection curve could be drawn by considering these moments as loads and computing a new moment diagram. This moment diagram of the conjugate beam would be the deflection curve of the ship. As stated before, coincidence of this curve with the profile of the ship indicates the accuracy of the solution.

CONCLUSIONS
AND
RECOMMENDATIONS

The solution of the hinge reactions to obtain the influence lines is accomplished by an exact method since the drafts of two sections where they are connected by a frictionless pin must necessarily be equal. This solution is general insofar as it pertains to a series of identical sections, but the reactions for a series of sections of varying dimensions could easily be solved by the same method. As in any influence lines, these results hold for any system of loads, whether moving or static.

From these influence lines, it can be seen that the effect of a point load is greatest at the nearest hinge and that it is subject to a "damping" effect as the distance from the load position increases. The greatest reaction occurs when the load is at a hinge. When this is the case on a long series of sections, the reaction at the first hinge in either direction from the

loaded hinge is only 26.8% of the reaction at the load point. Similarly, the reaction at the second hinge is 7.18%, at the third, 1.93%, and at the fourth, 0.55%. Thus it is evident that if an accuracy of 10% is desired, only two hinges from the load point need be considered, and if 1% accuracy is desired, only four hinges from the load point need be considered.

This solution is valuable not only in the analysis of hinge reactions of sectional floating drydocks but also in problems involving any series of pontoons connected by hinges. As recalled by Mr. A. Amirikian, at one time the construction of floating landing mats was contemplated. These were to consist of series of large pontoons with flexible connections. With the influence lines found above and with the wheel loads of the plane, the hinge reactions could be found, and the profile which would meet the pilot as he lands at any particular point could easily be determined.

The accuracy of the solution of the problem depends not only upon the method chosen for the

solution of the simultaneous equations but also upon the number of places to which the results are carried. It is felt that the accuracy carried throughout the work is sufficient to permit the necessary degree of accuracy in the results.

In the second part of the work, the loading was derived from weight distribution curves obtained from the Bureau of Ships. The results of this part depend primarily upon the loading used, and therefore the degree of refinement of the weight distribution curve is of the utmost importance in obtaining accurate results.

Since the optimum condition for the drydock under load is that of a horizontal profile, the assumption that each section supports that part of the ship which is directly above is indeed the case. It is therefore reasonable to assume that there is no shear carryover in the ship from one pontoon section to another.

The results obtained seem reasonable for the conditions assumed at the beginning of the analysis. This analysis was carried out for a

quiescent condition of the water, and this, of course, is seldom obtainable in nature. Even though it is generally assumed that these docks operate in sheltered harbors, there are still major effects from such natural causes as wind, currents, tidal currents, wave action, and cross-seas (wind and sea in opposite directions), These effects, furthermore, are vibratory, and the stress repetitions may cause failures akin to the fatigue failures evidenced in other structures.

The thesis entitled, "A Method of Investigation of the Strength in Bending in the Horizontal Plane of an AFDB when subjected to Lateral Wind, Current, or Wave Forces," by E. M. Saunders and W. W. Vander Wolk, Jr., considers some of the above effects on the semi-rigid sectional drydock, and especially the effect on the mooring system.

No consideration was given to loading other than along the longitudinal centerline of the dock. Large ships such as the one considered herein are normally docked along the centerline

of the dock, but smaller ships might be and occasionally are docked in groups so that no ship has its keel over the longitudinal centerline. At times the groups of ships are not moored abreast, therefore the load distribution would not be transversely symmetrical about the longitudinal centerline. These effects are not insignificant.

The given case which was considered to demonstrate a method of solution consisted of a specific naval vessel placed on the dock which in turn was ballasted in a particular manner. The results obtained from this solution seemed feasible for the stated conditions, but as shown above, the practicality of these results is somewhat limited. It is recommended that in any further investigation of this structure some consideration be given the effects of wind and sea. In other words, it would be better to set up the conditions to give results which are as practical as possible. Perhaps an approach which considers first the allowable bending moment and attempts to determine the maximum deflections of the dock which would not cause this value to be exceeded would be of considerable value.

It is further recommended that any advancement of this work consider practical pumping procedures as to compartmentation and sequence of operation.

Since all connections between sections are subject to considerable stress induced by working of the dock sections, these connections usually become inoperable preventing disassembly of the sections for towing. Design and recommendations concerning a more satisfactory connection would be of value.

If time and funds permitted, study of working models would probably be more beneficial than theoretical consideration since such a study would eliminate some of the necessary theoretical assumptions.

TABLE I

ORDINATES FOR INFLUENCE LINES OF HINGE REACTIONS

LOAD POSITION	Q_{12}	Q_{23}	Q_{34}
1	.26794919	.07179677	.01923788
2	.53589838	.14359354	.03847577
3	.46410162	.14359354	.03847577
4	.12435565	.50257774	.13466520
5	.12435565	.49742226	.13466520
6	.03332100	.13328401	.50018504
7	.03332100	.13328401	.49981496
8	.00892837	.03571349	.13392507
9	.00892837	.03571349	.13392507
10	.00239234	.00956938	.03588517
11	.00239234	.00956938	.03588517
12	.00064104	.00256422	.00961564
13	.00064104	.00256422	.00961564
14	.00017183	.00068730	.00257739
15	.00017183	.00068730	.00257739
16	.00004626	.00018504	.00069391
17	.00004626	.00018504	.00069391
18	.00001322	.00004287	.00019826
19	.00001322	.00004287	.00019826
20	.00000661	.00002643	.00009913

TABLE I (Continued)

ORDINATES FOR INFLUENCE LINES OF HINGE REACTIONS

LOAD POSITION	Q_{45}	Q_{56}	Q_{67}
1	.00515478	.00138121	.00037009
2	.01030955	.00276243	.00074017
3	.01030955	.00276243	.00074017
4	.03608343	.00966851	.00259061
5	.03608343	.00966851	.00259061
6	.13402416	.03591160	.00962225
7	.13402416	.03591160	.00962225
8	.50001321	.13397790	.03589838
9	.49998679	.13397790	.03589838
10	.13397129	.50000000	.13397129
11	.13397129	.50000000	.13397129
12	.03589838	.13397790	.49998679
13	.03589838	.13397790	.50001321
14	.00962225	.03591160	.13402416
15	.00962225	.03591160	.13402416
16	.00259061	.00966851	.03608343
17	.00259061	.00966851	.03608343
18	.00074017	.00276243	.01030955
19	.00074017	.00276243	.01030955
20	.00037009	.00138121	.00515478

TABLE I (Continued)

ORDINATES FOR INFLUENCE LINES
OF HINGE REACTIONS

LOAD POSITION	Q_{78}	Q_{89}	Q_{9-10}
1	.00009913	.00002643	.00000661
2	.00019826	.00005287	.00001322
3	.00019826	.00005287	.00001322
4	.00069391	.00018504	.00004626
5	.00069391	.00018504	.00004626
6	.00257739	.00068730	.00017183
7	.00257739	.00068730	.00017183
8	.00961564	.00256417	.00064104
9	.00961564	.00256417	.00064104
10	.3588517	.00956938	.00239234
11	.03588517	.00956938	.00239234
12	.13392507	.03571349	.00892837
13	.13392507	.03571349	.00892837
14	.49981496	.13328401	.03332100
15	.50018504	.13328401	.03332100
16	.13466520	.49742226	.12435565
17	.13466520	.50257774	.12435565
18	.03847577	.14359354	.46410162
19	.03847577	.14359354	.53589838
20	.01923788	.07179677	.26794919

TABLE II

Section	Load Kips	Center of Gravity from left end	Eccentricity from center line	Ballast
1	2,001.0	54.88	14.13 R	10,170.4
2	5,575.3	47.68	6.18 R	6,596.1
3	10,388.2	40.58	0.92 L	1,783.2
4	11,739.7	44.06	2.56 R	431.7
5	12,171.4	41.75	0.25 R	0
6	11,748.9	40.24	1.26 L	422.5
7	9,930.3	41.03	0.47 L	2,241.1
8	10,030.0	37.59	3.91 L	2,141.4
9	4,878.5	24.42	17.08 L	7,292.9
10	2,469.4	40.99	0.24 R	9,702.0

TABLE III

ORDINATES AT POINTS OF CONCENTRATED LOAD

	1	2	3	4	5
Q_{12}	-.2733	+.1260	-.0413	+.0109	-.0032
Q_{23}	+.0732	-.2276	+.1890	-.0436	+.0129
Q_{34}	-.0196	+.0610	-.1756	+.1634	-.0485
Q_{45}	+.0053	-.0163	+.0471	-.2025	+.1811
Q_{56}	-.0014	+.0044	-.0126	+.0543	-.1949
Q_{67}	+.0004	-.0012	+.0034	-.0145	+.0495
Q_{78}	-.0001	+.0003	-.0009	+.0039	-.0133
Q_{89}	0	-.0001	+.0002	-.0010	+.0035
Q_{9-10}	0	0	-.0001	+.0003	-.0009

	6	7	8	9	10
Q_{12}	+.0009	-.0002	+.0001	0	0
Q_{23}	-.0037	+.0010	-.0003	+.0001	0
Q_{34}	+.0138	-.0036	+.0011	-.0004	0
Q_{45}	-.0516	+.0134	-.0041	+.0016	-.0002
Q_{56}	+.1927	-.0500	+.0153	-.0060	+.0007
Q_{67}	-.1734	+.1866	-.0570	+.0224	-.0025
Q_{78}	+.0464	-.1794	+.2127	-.0837	+.0094
Q_{89}	-.0124	+.0478	-.1524	+.3124	-.0353
Q_{9-10}	+.0031	-.0120	+.0381	-.0480	+.1316

TABLE IV and V

SHEARS, kips

HINGE	NO BALLAST	BALLAST
1-2	- 237.57	- 318.03
2-3	+ 450.71	- 514.81
3-4	- 61.15	- 29.16
4-5	- 271.91	- 44.32
5-6	+ 169.46	- 9.43
6-7	- 191.03	+ 293.28
7-8	+ 389.42	- 254.38
8-9	+ 271.56	+ 674.39
9-10	+ 378.29	+ 132.54

TABLE VI

MEAN DRAFTS

HINGE	NO BALLAST	BALLAST
1-L	6.78	15.03
1-2	8.87	15.67
2-3	13.77	16.70
3-4	14.37	14.86
4-5	16.23	16.38
5-6	16.08	15.99
6-7	14.32	15.52
7-8	14.75	16.14
8-9	13.43	16.77
9-10	7.12	14.12
10-R	9.01	16.61

TABLE VII

	Resultant Force	Moment	Modified Moment
1	- 308.53	0	0
2	- 190.90	25,608	25,608
1/8 point			30,790
			22,474
3	+ 471.15	67,061	48,950
4	- 14.71	69,408	50,663
3/8 point			51,640
			35,730
5	+ 33.85	72,976	36,857
6	+ 311.75	73,735	37,240
5/8 point			29,312
			42,563
7	- 549.37	48,618	35,488
8	+ 942.58	69,099	50,438
7/8 point			13,551
			18,565
9	- 559.06	11,346	11.346
10	- 136.76	0	0

Whole numbers refer to center of pontoons sections of corresponding number. Eighth points refer to sections of ship where I is considered to change value.

APPENDIX A

SOLUTION OF EQS. (11)

TABULAR METHOD

	2	3	4	5	6	7	8	9	10	11	12
.No.	Q_{12}	Q_{23}	Q_{34}	Q_{45}	Q_{56}	Q_{67}	Q_{78}	Q_{89}	Q_{9-10}	k	f
	8	2								0	10
	2	8	2							-4	16
		2	8	2						-2	14
			2	8	2					0	12
				2	8	2				0	12
					2	8	2			0	12
						2	8	2		0	12
							2	8	2	0	12
								2	8	0	10
:1-2	0	-30	-8							-16	-54
:10-3		0	112	30						14	156
:-11-4			0	418	112					-14	516
:-12-5				0	1560	418				14	1992
:-13-6					0	5822	1560			-14	7368
:-14-7						0	21728	5822		14	27564
:-15-8							0	81090	21728	-14	102804
:16-(-9)								75658	0	-14	75644

SOLUTION OF EQS. (11)
BY
TABULAR METHOD (Continued)

1	2	3	4	5	6	7	8	9	10	11	12
(1)	8	2								0	10
(2) x-4	-8	-32	-8							-16	-64
(10)	0	-30	-8							-16	-54
(3) x15		30	120	30						30	210
(11)		0	(-)112	(-)30						(-)14	(-)156
(4) x56			112	448	112					0	672
(12)			0	(-)418	(-)112					(-) -14	(-)516
(5) x209				418	1672	418				0	2508
(13)				0	(-)1560	(-)418				(-)14	(-)1992
(6) x780					1560	6240	1560			0	9360
(14)					0	(-)5822	(-)1560			(-) -14	(-) 7368
(7) x2911						5822	23288	5822		0	34932
(15)						0	(-)21728	(-)5822		(-)14	(-)27564
(8) x10864							21728	86912	21728	0	130368
(16)							0	81090	21728	-14	102804
(9) x-2716								-5432	-21728	0	- 27,160
(17)								75658	0	-14	75,644

From Eq. 17 above, $75658Q_{89} = -14$ or

$$Q_{89} = \frac{-14}{75658} = -.00018504322$$ and other shears

can easily be found by substitution in the above formulas.

APPENDIX B

TYPICAL SOLUTION FOR DRAFTS -
NO BALLAST CONDITION

$$D_{23} = d_{W2} + d^{i}_{23} + d^{ii}_{23} - d^{iii}_{23} + d^{iv}_{23} + d^{v}_{23} + d^{vi}_{23}$$

$$d_{W2} = \frac{W_2}{wbL_2} = \frac{8534.4}{.064 \times 256 \times 80} = 6.5112304 \text{ ft.}$$

$$d^{i}_{23} = \frac{P_2}{wbL_2} = \frac{5575.27}{1310.72} = 4.25359 \text{ ft.}$$

$$d^{ii}_{23} = \frac{6P_2e_2}{wbL^2_2} = \frac{6 \times 5575.27 \times 6.1836}{1310.72 \times 80} = 1.97269 \text{ ft.}$$

$$d^{iii}_{23} = \frac{Q_{12}}{wbL_2} = \frac{237.57448387}{1310.72} = 0.18125494 \text{ ft.}$$

$$d^{iv}_{23} = \frac{3Q_{12}}{wbL_2} = 0.5437648 \text{ ft.}$$

$$d^{v}_{23} = \frac{Q_{23}}{wbL_2} = \frac{450.71304}{1310.72} = 0.34386676 \text{ ft.}$$

$$d^{vi}_{23} = \frac{3Q_{23}}{wbL_2} = 1.031600299 \text{ ft.}$$

$$\begin{aligned} D_{23} &= 6.5112304 + 4.25359 + 1.97269 + 0.1812549 \\ &\quad - 0.5437648 + 0.34386676 + 1.031600299 \\ &= 13.75404676 \text{ ft.} \end{aligned}$$

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DATE DUE

A study of stress
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